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Controls on lip elevation, lip-to-toe height and rate of face retreat of vertical knickpoints

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Vertical knickpoints with heights that exceed the flow depth range in scale from meters to several hundred meters and are common in steep bedrock channels. They carry tectonic and eustatic signals upstream and can set landscape response time to such perturbation. Marking a discontinuity in channel elevation vertical knickpoints also delineate a prominent process transition zone. Therefore, conventional stream-power incision models are insufficient to capture the essential physics of their retreat.

We examine the evolution of vertical knickpoints with resistant caprock utilizing numerical simulations which explicitly represent: (1) face failure mechanisms, (2) flow acceleration and amplified erosion above a knickpoint lip, (3) deposition and removal of coarse debris below the knickpoint and (4) base level lowering or tectonic uplift rates.

Our model demonstrates that long-term weathering-limited knickpoint retreat rate decoupled from channel lowering rate is possible. The model also shows that the lip-to-toe height of a knickpoint and its lip elevation may remain transient for long periods despite constant rates of base level lowering.

Two types of oversteepened reaches are often associated with a vertical knickpoint. An upstream, freefall-induced, oversteepened reach whose length is longer than the flow acceleration zone can form above a knickpoint lip and a debris-induced oversteepened

reach can form below its toe. The model illustrates that the length and the fluvial relief of both of these oversteepened reaches can vary over time in a predictable manner but may also reach steady state.

If the ratio between the weathering rate of the face and incision wave velocity above the lip varies with discharge, the rate of change of a knickpoint lip elevation can depend on the knickpoint location within a drainage basin. For example, lip elevation can increase rapidly when the knickpoint is located close to the basin outlet but decrease as the contributing drainage area above the knickpoint drops below a certain threshold.

Though the model was built with caprock-type knickpoints in mind, similar process interactions are expected in homogenous substrate and can yield time-dependent lip elevation, lip-to-toe height and channel gradients upstream of the knickpoint lip and below its toe.